Proceeding of the IHPST, Denver, 2001.
www.ihpst.org

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Stephen E. Toulmin's contribution to science and science education:

A field report on the innovation in tools for education that make explicit the warrants used and the nature of argument-assessment and thus build epistemic knowledge.

Abstract

In this period of rapidly changing technologies and the re-integration of newly forming disciplines the nature of modern science has become a process of scientific discovery described by Toulmin in his many books and understood in its form of discourse from *The Uses of Argument*. This paper reviews the effect of Toulmin's work on the design of computationally based pedagogical tools. Three examples of tools are presented. In this paper there is an integration made demonstrating that these tools are consistent with the movement in science to the use of models as part of the essential triad that drives scientific questions and discovery. The function in science of models and the function in education of the computational tools described are show to function in a manner described by Toulmin.

Introduction

This paper is a field report on the pragmatic outcomes for science and science education of the notions put forward by Stephen E. Toulmin, notably in the Uses of Argument (Toulmin 1958). The paper takes its view with special emphasis from within recent innovations in fields often-utilizing computationally intense methodologies; and applies that view to science education with computationally based tools. For illustration we do not include all such tools, but ones that are historically and functionally developing from a common notion of the nature of science as Toulmin's recent books detail, and as the nature of the scientific discourse is a form of argument-meaning making of a juridical form; as Toulmin explains in *The Uses of Argument (Toulmin 1958)*. The tools we will look at include over a decades worth of work beginning with the knowledge network known as CISLE (Scardamalia 1994), the Collaboratory Notebook (Edelson 1995), the graphical version of a Toulmin persuasive/meaning construction tool by Project Belvedere (Suthers 2001); and finally a general purpose modeling tool developed for new learners and non-numerical concepts (Shari L. Jackson 1995). The paper will move along the history of these tools to make explicit the nature of the scientific process embedded in the tools The paper will end with a look at common modeling tools to demonstrate that for more expert learners, models serve the same functions as these pedagogically explicit tools, and that modeling and visualization provide the modern form of juridical persuasion that is essential to science, as Toulmin (Toulmin 1958) has made clear.

The Common Basis for Science Tools supporting Science Discourse

The argument is made that there is a common basis for what has turned out to be a very pragmatic utility of Toulmin's philosophical notions that can be found in the history of this new field of model creation, knowledge or concept mapping, visualization and scaffolled supports for scientific argumentation. Further these common fundamental features are now applied in many highly effective educational science and math projects seen in K-12 and college education (Kelly and Lesh 1999). That both science and science education can be shown to have benefited from the understanding of argument-assessment as raised by Toulmin is the central thesis of this paper.

The recent developments of tools for education based directly on new insights into the new sciences are transforming whole programs of study, especially in K-8, in undergraduate and post-graduate programs. Visualization and Modeling systems are a now a common tool for scientists and students alike. Fortunately the power of these new educational tools and innovation in scientific informatics such as data mining and knowledge management are occurring rapidly and thus science educators need to be very much aware that they practice, their black arts, during a period of much change. For example there is increasing re-integration of the fields of science leaving behind the traditional disciplines as an object for curriculum attention. Plus the rapid developments of media rich text book substitutions and the creation of enabling technologies such as peer to peer desktop tools will displace what we have just gotten used to, mainly server-based enhancements of integrated supportive tools. As I had suggested in my 1997 prediction of the world of enhanced pedagogical use of the internet in a SuperWeb for Education (Zaritsky 1997) it turns out that Napster will be the model for dissemination not central servers and services. But I digress. For this paper it is important to understand that these peer to peer tools seem to be informed by the current research on collaborative systems. So both a researchers and technologists it is necessary for us to pull apart features of the cognitive components of the tools, their forms of visualization, whether or not they are shared in collaborative space and whether it they facilitate continued annotation and commentary (Suthers 2001) (Zaritsky 1997). The goal would be for us to recognize the essential features that should be included in the new peer-to-peer based tools. [1]

The design of pedagogically effective tools cannot solely be considered an issue of creating scientific discourse of the sort noted by Toulmin. Certainly each domain of science is being re-created with new tools and new driving questions. The well worn modes of instruction may no longer serve. Roschelle & Kaput had suggested we should be forced to transform our notions of the science in creating pedagogically appropriate tools (Roschelle & Kaput, 1994). Further, this speed of change in science and the supporting technologies are a real challenge for science educators. However, as I shall make clear here, the features of science, such as the provision of explicit warrants found in Visualizations or Models will still be required as effective components in the discourse of science and the creation of paths and tools for new learners. This fits with Suthers finding that:

> "Existing computer mediated communication tools [are] particularly deficient in supporting artifact-entered discourse."

Suthers proposes that artifacts such as Visualizations be coordinated with the epistemic disciplinary structure and the manner in which knowledge is represented. His proposed solutions are pedagogically effective tools of the sort that we examine below. (Suthers 2001)

In brief, this paper points out that Suthers most specifically and the other tool designers demonstrated are basing their notions on explicit features of Toulmin's analysis of scientific discourse and its goals and processes as they design these new pragmatic tools in education. Further many of the new tools for scientists such as the Biology Workbench are developing student versions that help scaffold new users by making the argumentation features explicit within the tutorials (Jakobsson 2001). Thus in education, pragmatic effective results for the learner are to be obtained by making the components of argument-assessment explicit: first, by attempting a persuasive argument, in a specific science domain; to assert from some controversy a position. And

[1] While educational research continues to develop pedagogically motivated collaboration systems or spaces, if you will. At the same time we are seeing a notable and highly scalable new developments in generic collaboration spaces that work peer to peer like the Napster successors. While this is a technical aside, it is worth the note. A free commercial tool is found at www.groove.net. This paper was written within Groove ™ on all of the four computers that are networked around my house. Groove ™ makes it possible for me to have a common working space that I could open on any computer, while others were busy producing new DVD's as part of a project on Educational Research Visualizations.

second, to provide as the nature of evidence such warrants that can be brought to that argument. Usually these are through Visualizations and quotation, but they may be through functional models. Thus to briefly summarize Toulmin's notions, science is a persuasive process of argument meaning-making and assessment that is juridical in function; determining what is believable (veritas) not what is absolute fact. For education, new tools make explicit to the learner the above components with a mix of graphical and labeling aids, as are demonstrated below, and thus they support a fundamental reform of science instruction and learning. In brief this paper will show that advanced sciences and educational innovations for learners have benefited directly from the uses of these concepts explicated by Toulmin.

This paper will in part chronicle the history of these most recent tools developed in part by Toulmin's students and their students. We shall look at three tools in the order of their creation beginning with CSILE from 1994 and ending with today's modeling tools for learners.

A Brief Survey of the Features of Three Argumentation/Meaning-Making Tools

CSILE

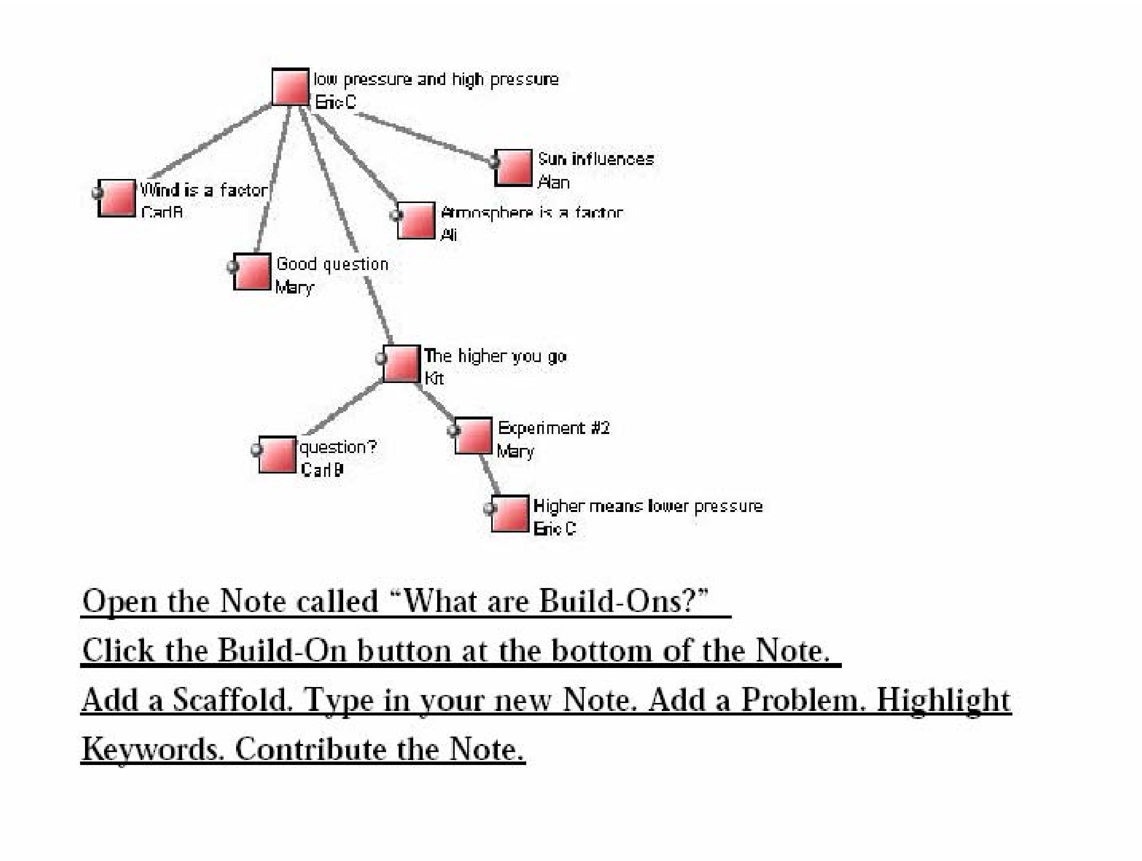
Scardamalia & Breiter described CSILE as

> "…a means for reframing classroom discourse to support knowledge building in ways extensible to out-of-school knowledge-advancing enterprises. [and } focuses on the educational ideas for knowledge building discourse … CSILE as a design … functions to solve three concerns in pedagogical research and thought. Some of the most fundamental problems are logistic, and it is in solving these logistic problems that we see the greatest potential for educational technology.
> (Scardamalia 1994)

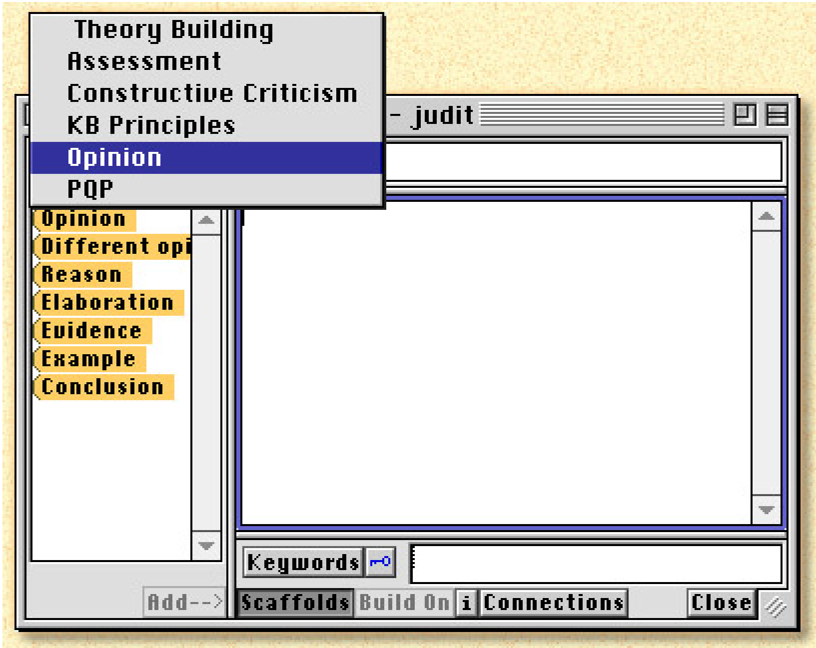
Scardamalia suggests that the three concerns for pedagogical research are:

- Intentional learning.
- The process of expertise.
- Restructuring schools as knowledge-building communities.

CSILE address all three concerns but providing a Community Database at the Center of Classroom Discourse created by students. The database is organized, as we see below as a knowledge network. The network functions for the students to help them locate both where knowledge is contained, and who in their community, within and outside the school has researched and added that research to the knowledge network. So as its first feature, CSILE forms the discourse in this tree like structure.

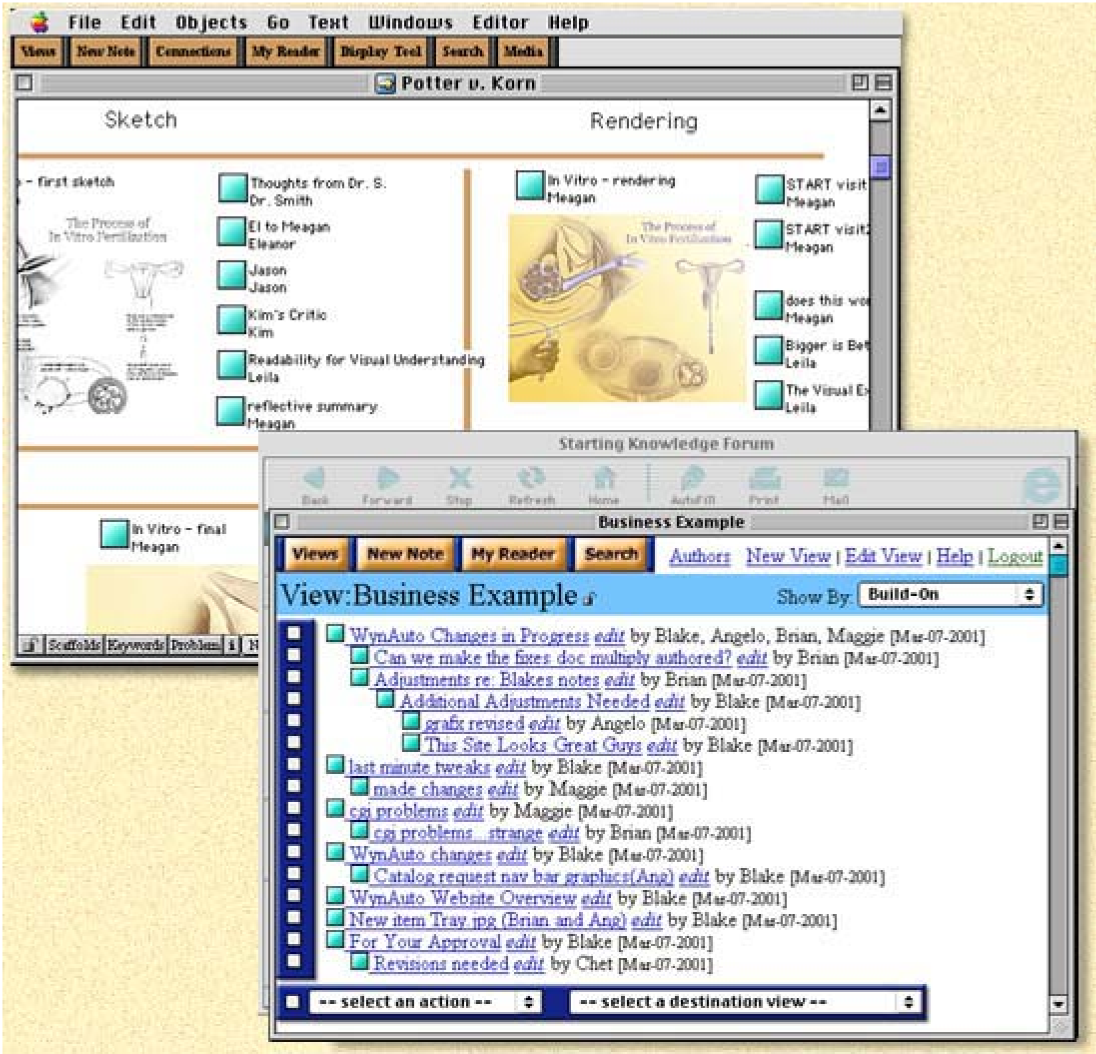


Secondly, it is necessary for the various warrants, or evidence, to be provided. In this screen we can see that Theory statements and their warrants can be detailed as Theory Building, as assessment statements, as constructive criticism, as opinion and elaboration or examples.

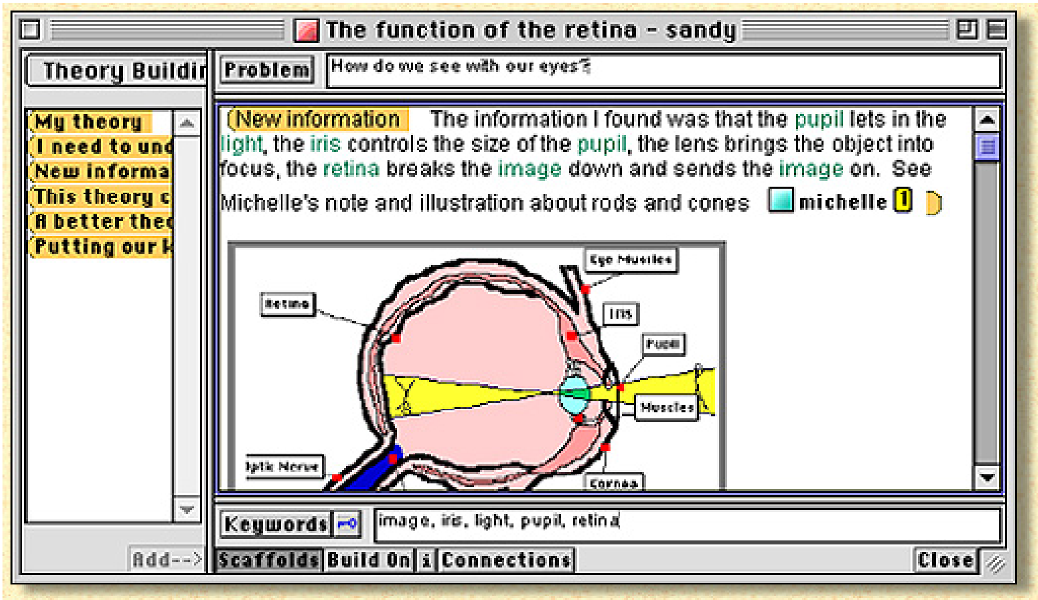


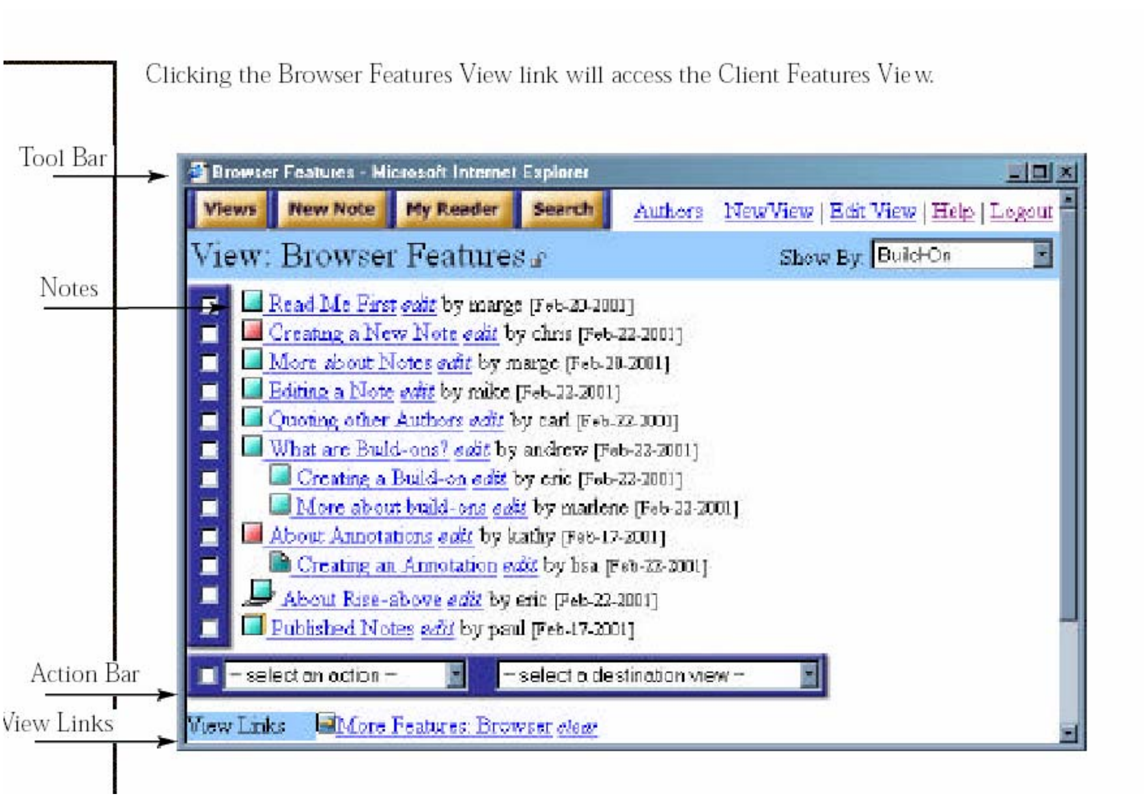
In evaluations of CSILE to date. Scardamalia reports that

> "CSILE students greatly surpass students in ordinary classrooms on measures of depth of learning and reflection, awareness of what they have learned or need to learn, and understanding of learning itself. Moreover, individual achievement, as conventionally measured, does not suffer. In fact, students do better on standardized tests in reading, language, and vocabulary (Scardamalia et al., 1992). What most impresses teachers and observers alike, however, is what the students are able to do collectively. As the preceding examples suggest, they seem to be functioning beyond their years, tackling problems and constructing knowledge at levels that one simply does not find in ordinary schools, regardless of the calibre of students they enroll. "
> (Scardamalia 1994)



The figures above show the form of the detailed presentation of evidence and the manner of viewing a knowledge forum as a hypertext set of threads.

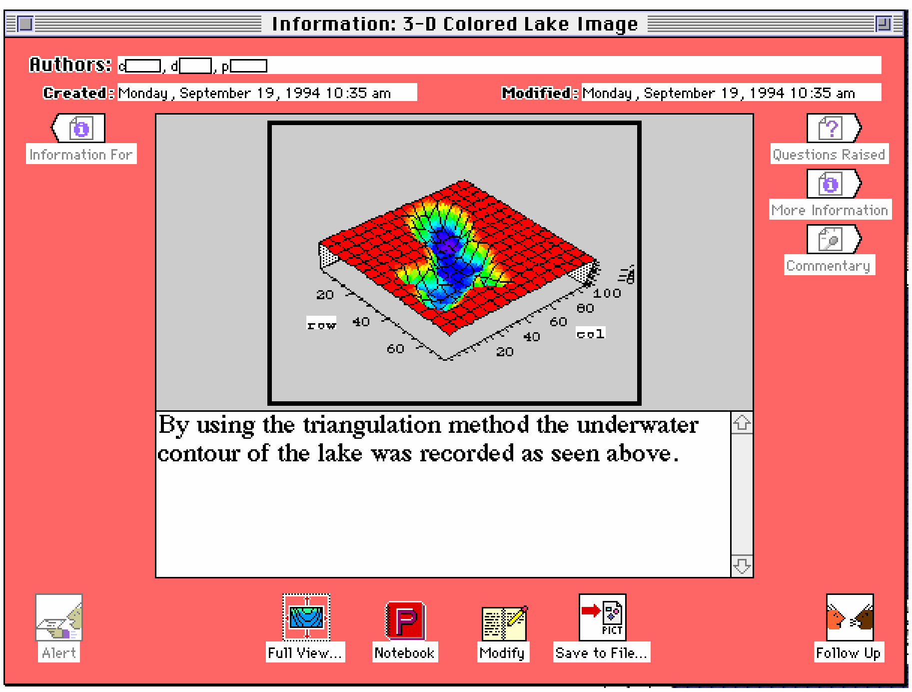


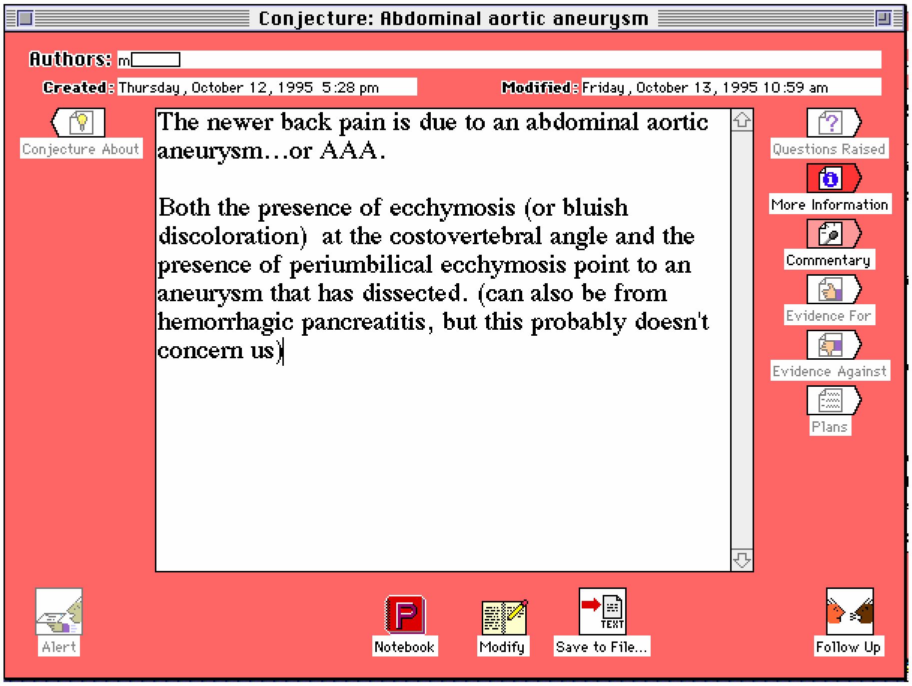


While not arguing that these tools will by themselves transform school learning, Breiter and Scardamalia do suggest that students can share knowledge with one another in a form that facilitates the process of scientific discourse as a persuasive meaning-making task. Originally these tools were packaged by Apple and sold as a product. They obviously required an underlying database on a server be maintained to assure that the knowledge network was available on a year-to-year basis. As so much technology has changed since 1994, the tool has changed to a web-based version and the server functions remain an issue for sustainability.

Collaboratory Notebook

Another version of a pedagogically constructed tool that makes explicit the nature and features of science discourse and persuasive meaning-making is the Collaboratory Notebook by Edelson and O'Neil created as part of the CoVis project one of whose P/I's is Toulmin's former student Roy Pea (Roy D. Pea 1994). The Collaboratory Notebook is a next generation version of a community shared science discourse tool.





The above pages from the database of the Collaboratory notebook show the explicit nature of the various forms or types of components one can add to the discourse. Going down the buttons on the right side of the screen one can see that the form taken by the database is very clearly a transformation into a tool of Toulmin's components of argumentation. Going down the right side:

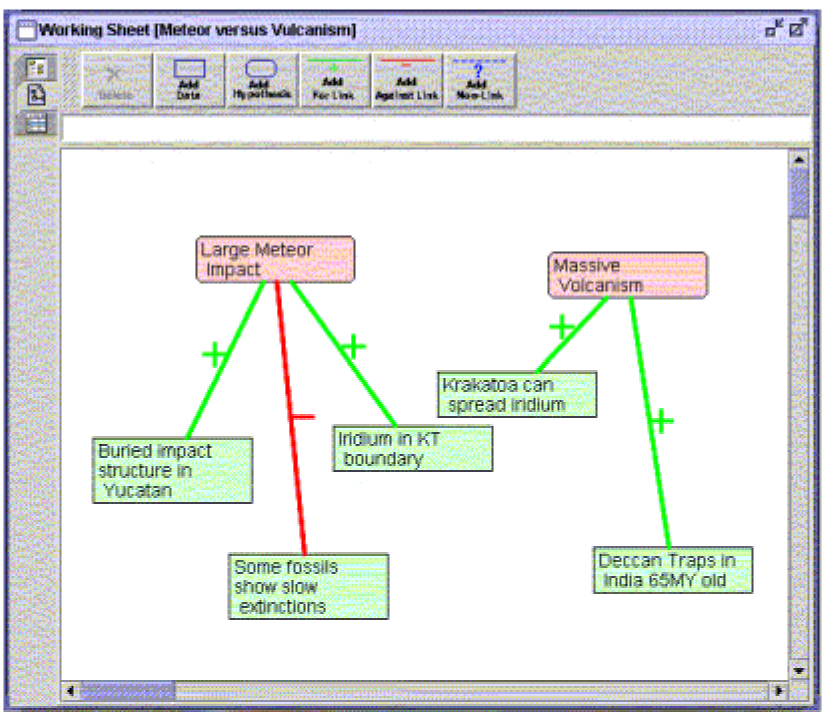
- There is the Larger Question Raised
- The page that provides more information about the question
- The page for commentary
- The page where one puts evidence for the hypothesis
- The page where one puts evidence against the hypothesis
- The page where one plans one's next steps for investigation and analysis

When the Collaboratory Notebook was use with Medical Students, as seen in the second screen shot, the form was slightly changed so that argumentation scaffolds were replaced with the pbl (Problem Based Learning) structure of the problem and the effect was highly successful in this medical school use. This demonstrates that the nature of the pedagogical scaffolds needs to be adjusted to the expertise of the user and the problem domain.

As an important technical aside, I again want to mention that in practice the Collaboratory Notebook is dependent on a server model for sustainability. When the server at Northwestern University's site is no longer available the tool is lost. Again this is the issue of peer-to-peer based tools versus server-based tools. All three tools described here are based on server functionality.

Belvedere

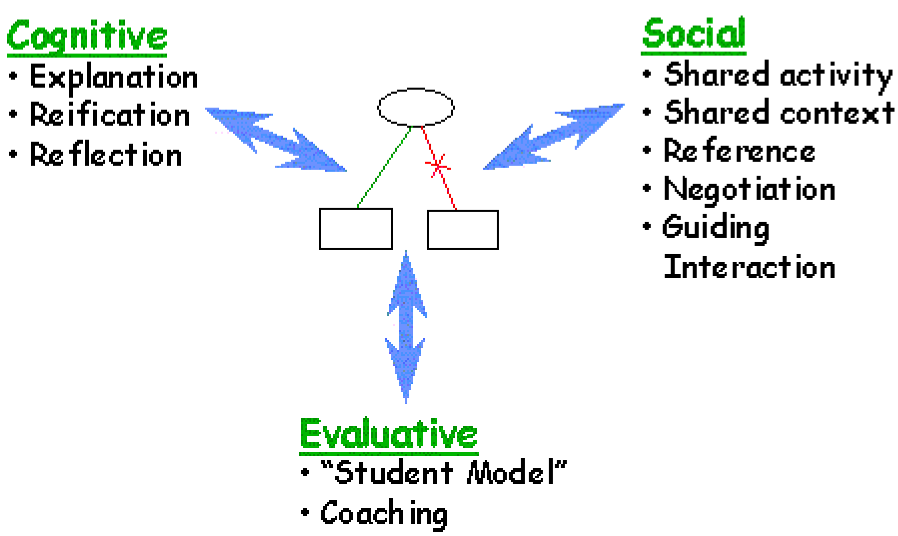
The Belvedere designs are the most recent and current tool. Belvedere also was explicitly created with a copy of Toulmin's ***Uses of Argument*** out and available. In this case the primary form of the discourse is represented graphically. The driving question or hypotheses being understood is whether a large meteor impact or massive volcanism accounts for the very large crater in the ocean near the Yucatan peninsula. In this version of the software, the two competing hypotheses are inside the rounded forms. The evidence is inside green square boxes. And lines are drawn from the evidence to the hypothesis with a plus mark or a minus mark indicating whether the evidence supports or contradicts the hypothesis.



In creating Belvedere, Suthers and his team noted that the other tools used what seemed like a container representation, as we see in the Collaboratory Notebook above. Suthers was concerned that this may not be the right representation for students using a collaborative construction of evidence tool. Thus Suthers suggests that explicit research engage the question of the exact nature of the form of the representation providing guidance. In its current form, Belvedere uses both a graphical and a table format. The research on which representational mode is most effective has yet to be completed.

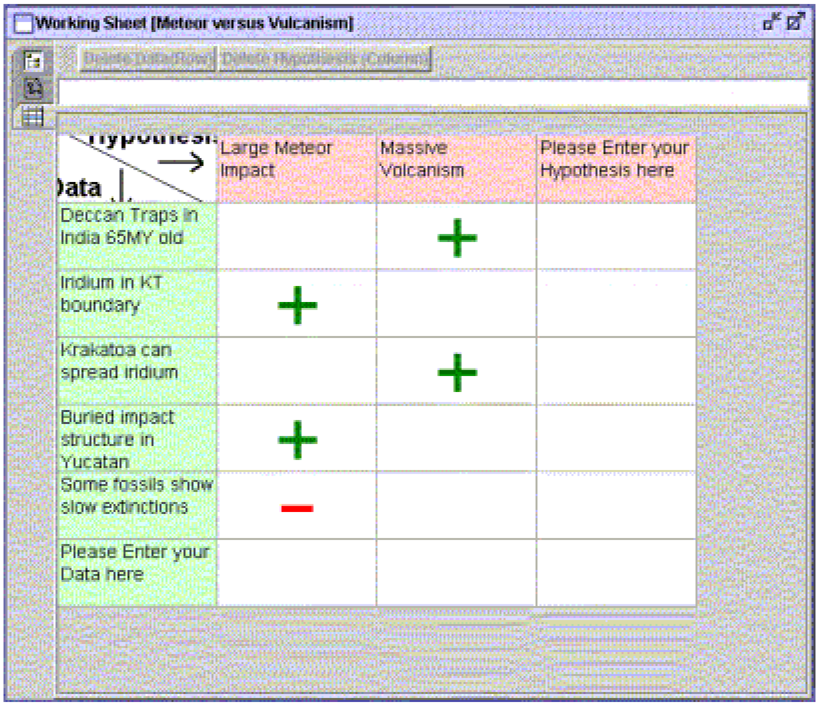
> However, few systematic comparisons of the effects of representations on collaborative learning had been undertaken. Exceptions include Baker & Lund (1997) and Guzdial (1997). Theoretical inspirations for such a comparison came from Roschelle's (1994) observation that shared representations (animations and simulations in his case) serve to mediate collaborative inquiry; and from Collins & Fergusons' (1993) discussion of representations as "epistemic forms" with associated "epistemic games." Other literature suggests that representational guidance has it origins in constraints: limits on expressiveness, and on the sequence in which information can be expressed (Stenning & Oberlander, 1995) and salience: how the representation facilitates processing of certain information (Larkin & Simon, 1987).
> (Suthers 2001)

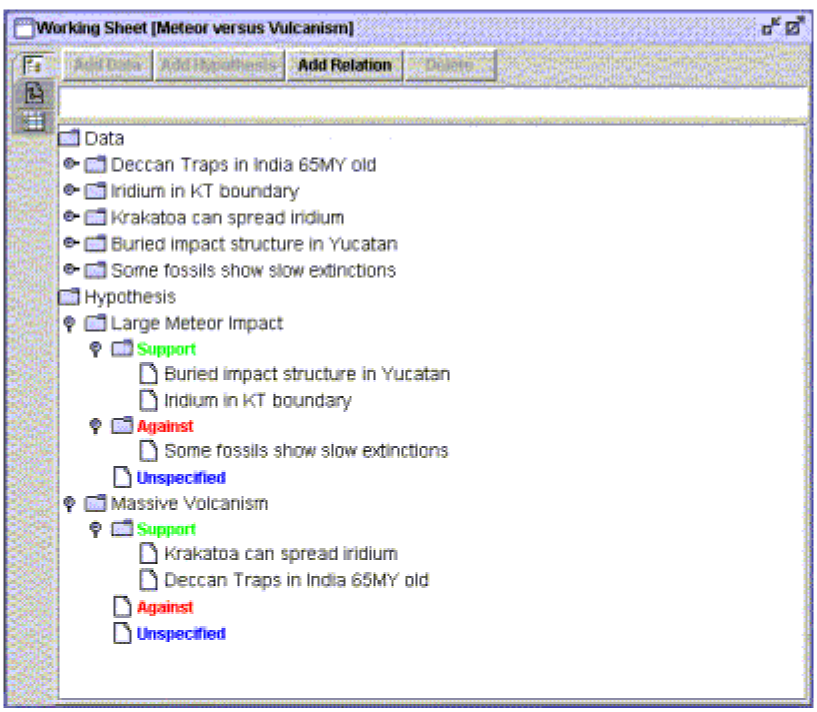
In creating a representation form, the features that Suthers notes must be part of the design are represented in his drawing:



(Suthers 2001)

Belvedere Supports Multiple views at present. The below images are work sheet versions of the same relationships constructed within the graphical form above.

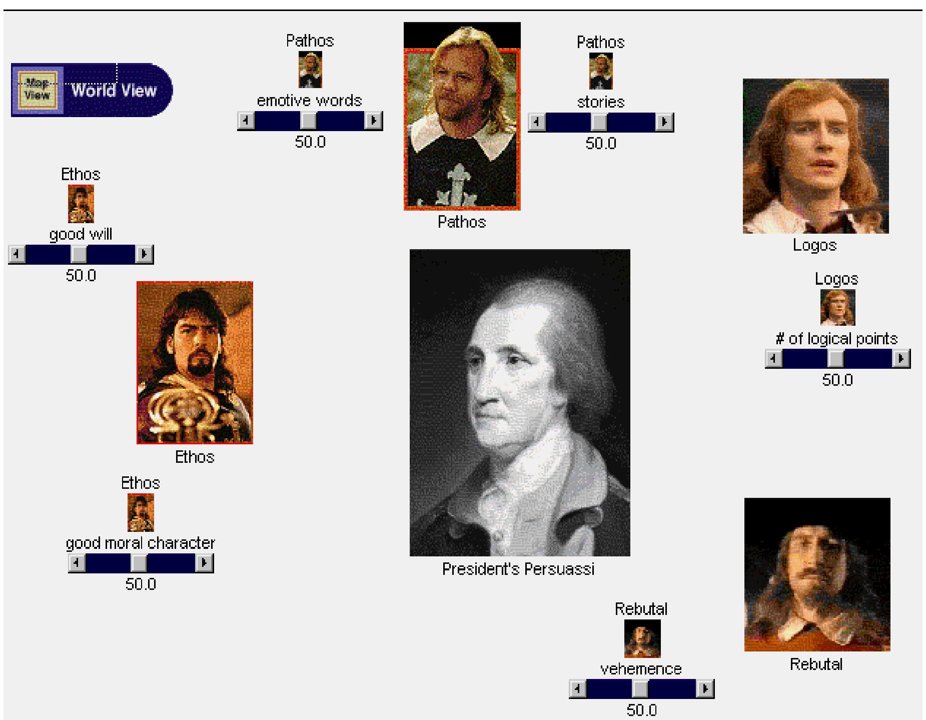




Models

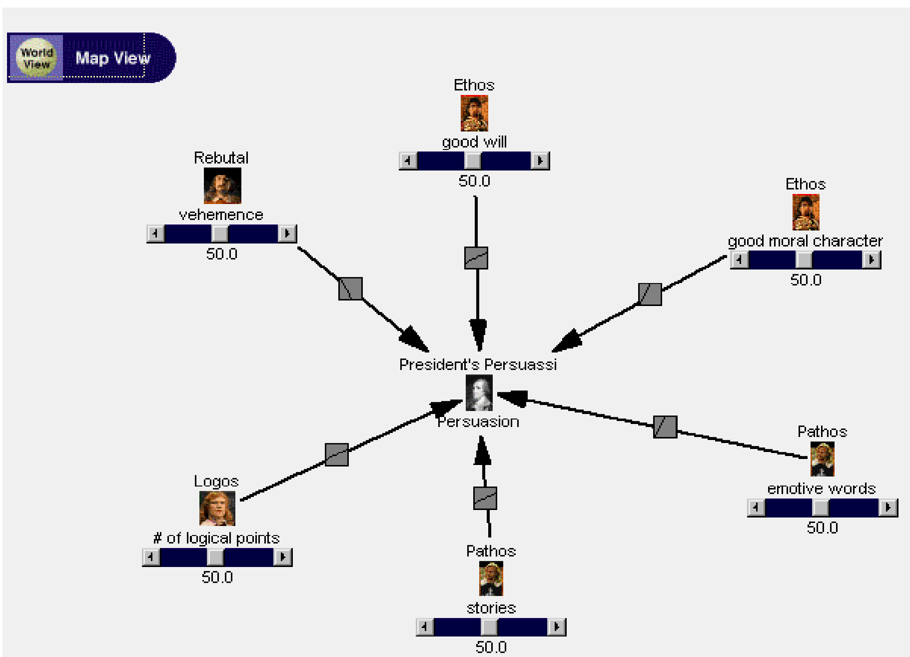
To make explicit a complete working model of one's notions of how a system functions is to create in the model the complete argument. Whether it persuades can be determined by how well the model represents real world phenomena or how well it predicts new phenomena. However, many complex human systems that are usually only described in a flat written format may be situated and made explicit and manipulability through models. In creating a model of a complex human system one is forced to make explicit the features that have function and the heuristics for their function that causes a systemic or local effect. Thus the model attempts the creation of a fully complete complex persuasive argument with the warrants both contained within the heuristics and determined by the fit to observation or prediction.

In this model created by a college teacher of rhetoric in my class on Modeling and Visualization the nature of persuasion is modeled. The dependent variable is the President's persuasiveness towards the American people. The actors are Pathos, Logos and Ethos, the classical view of rhetoric. Pathos the independent variable has functions represented by the amount of emotive words used and by the number of personal stories told. Logos has functions represented by the number of logical points and inversely by the amount of rebuttal. Ethos has functions from the good will of the people and the good moral character of the President.



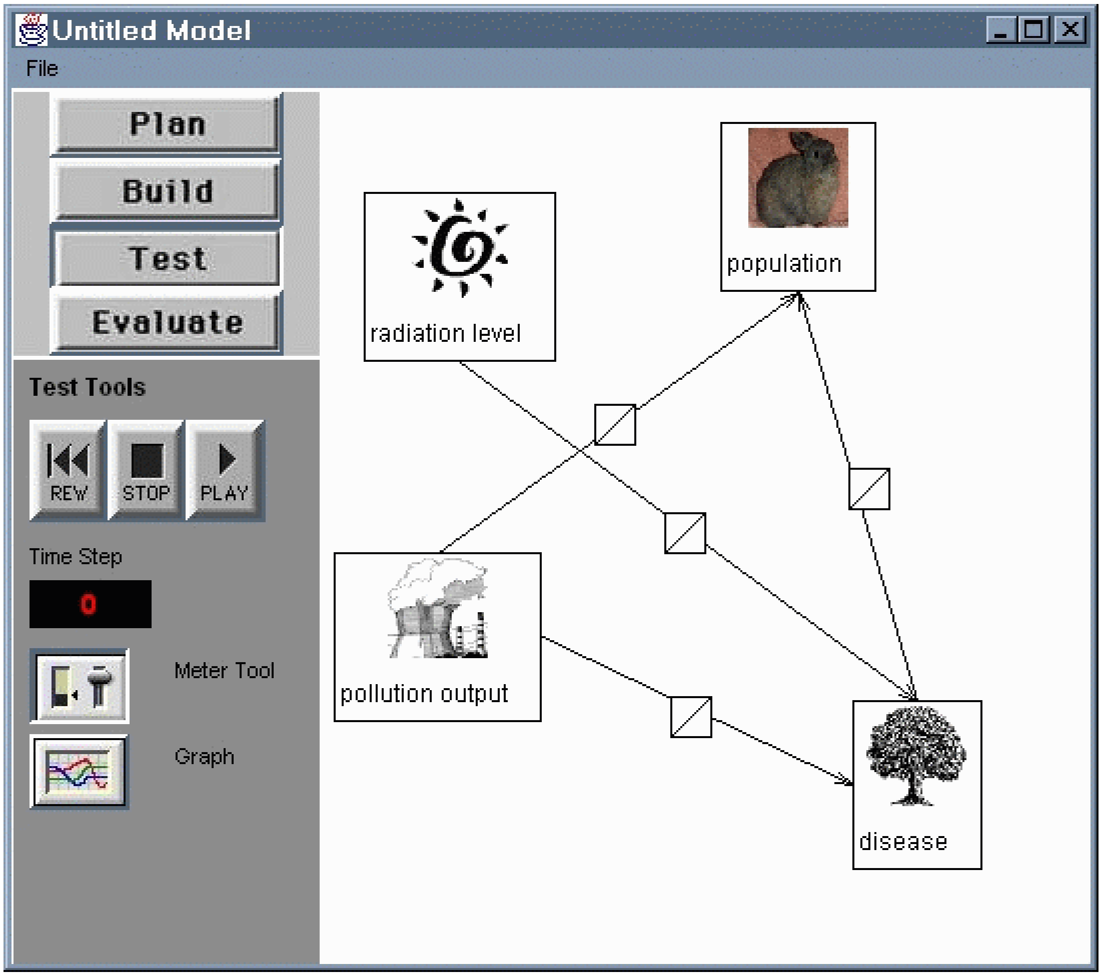
The second image shows the relationships. Running the model, as good will goes up (Ethos) and the number of emotive words and stories increase; the President's persuasiveness will increase. Running the model gives you a set of updating graphs, and then by moving the slider bars, you can change the situation. In the creation of the model shown below, if the amount of rebuttal increases and the good moral character of the President decreases then though the number of logical points goes all the way to full, still the President's persuasiveness was shown to decline over the first situation. This model was created during the crisis in the Clinton Presidency and was reported to be highly effective in engaging undergraduate students in the design and understanding of the classical rhetorical model.

Here one can argue that the situated ness of a very pressing national event and an effective modeling tool in the hands of a good teacher were able to significantly increase class participation over other classes in the course when the modeling tool was not used. (Zaritsky R. A 1999)

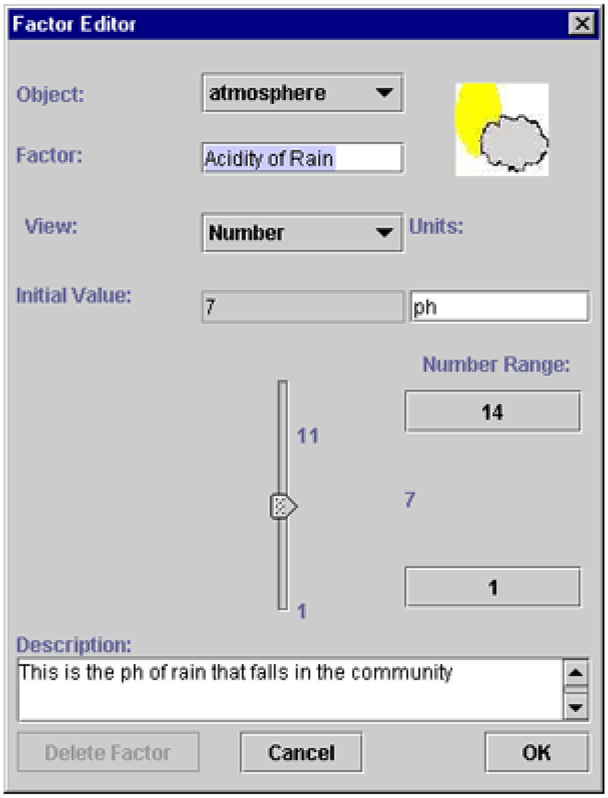


While modeling software has been an effective component of the scientist tool kit, versions of general purpose modeling software such as Stella have proven to be problematic for teachers and for some grades. Thus a simplified modeling software tool was created as part of the Hi-C group at the University of Michigan in Ann Arbor. An earlier version of Model-It was used in building the rhetorical model just seen.

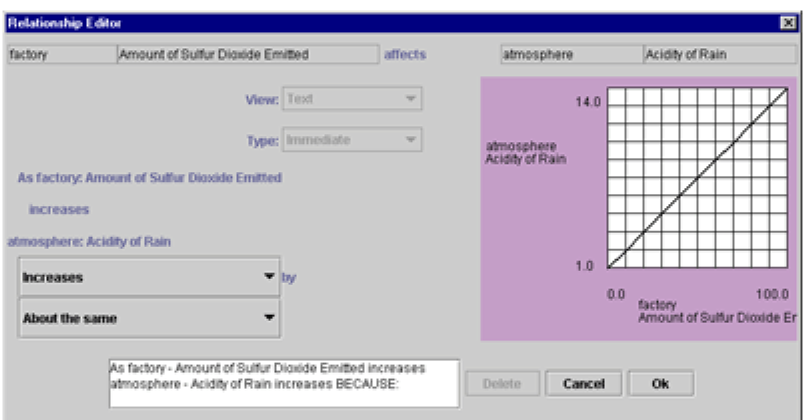
The current version developed by Shari Jackson and Elliot Soloway (Shari L. Jackson 1995) allows for a very graphical function between the independent and dependent variables. The current 2001 interface looks like the image below:



In each of the boxes between the variables one can see the graph of how that factor works. The main components such as radiation or atmosphere are constructed in a simple editor for the factor, or the variable, that allows one to set the initial value and to write in what the factor is about. Here the factor in the atmosphere is the ph of the rain as is written in the Description window

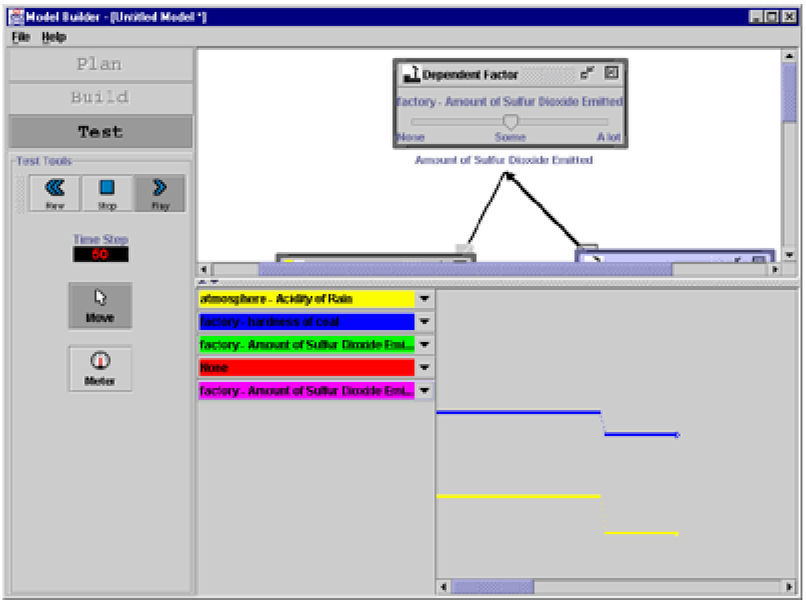


The inner programming of these factors is accomplished by the build editor:



The build editor says what the arithmetic relationship is between the variables. But it can be said in words that create the graph of the relationship.

The final effect needs to be interpreted by an interactive manipulation of the model and the viewing of the graphical representation of each of the variables.



This tool and other like it have been developed to work on the palm size platforms. For disease there is modeling software that works between palms called Cooties that shows how diseases are spread. The result is certainly a more affordable and possible set of tools for students in K-12. Amongst the most powerful is a simple version of the CSILE notion is a palm version of concept maps, called PicoMap.

Model-It has the effectiveness of all modeling tools, but since it was created to be used by teachers and students it is a very effective tool in creating meaning making and assessment in a scientific discourse in K-12.

Conclusion

The paper contends that the improved outcomes surrounding these new programs and their new tools in science education can in part be explained. Beginning with research showing widespread misuse of scientific argumentation by new science learners, researchers found that it is not the lack of facts that troubles students alone, but the poor use of “facts” as warrants for arguments in a scientific controversy for assessment.

Understanding that science has undergone a significant change with the development of computational technologies for modeling and data representation in a visual dynamic form. The result is that complex models and scientific visualizations have been added to the simpler dialectic between theories versus empirical data. Thus in much of science the real computer revolution is occurring through complex modeling and heuristics applied to data analysis. Thus this real revolution is not the communication revolution of the

Internet. The computational revolution is found more specifically in computational models, and their resultants: explicit shared methods of bringing the implicit meanings and assumptions of one single domain of science into public scrutiny by other domains. In fact the field has grown into distinct areas called Scientific Visualization including Modeling, Data Mining and Knowledge Management. Since computational methods make explicit in their construction the specific heuristics applied, diverse groups can assess the value of the fit of these heuristics to empirical data and meaning making. This satisfies Toulmin's description of scientific discourse.

The specific pedagogical tools presented above have also attempted to make explicit the nature of the discourse of science meaning making. They have accomplished this by supporting the explicit representation of the various warrants brought to the discourse and to the inter-relationships. The weight of support provided by the various warrants is made explicit through language and often through a graphical representation. In very much the same way the new sciences that rely on extensive modeling and Visualization, including Virtual Reality level computer images, have formed a method of argument that is in its effect on each domain very compelling. We believe that the nature of the importance of scientific modeling is explained by Toulmin's notions. Thus the models drive public discussion of the warrants and their application. Now all three (theory, empirical observation and computational models) are components of scientific argument-assessment and are interrelated to drive the set of questions in the domain. These are the notions of the scientific process that Toulmin predicts in U of A.

Education today needs to move from teaching science as groups of facts needing to be covered and related procedures and concepts needing to be mastered to a form of epistemic understanding by students in which knowledge is integrated with methods and facts into a persuasive form of student meaning making discourse. Whether these new educational innovations are called problem-based learning; project-based learning, innovative science design experiments the persuasive components of this discourse have been made explicit in many of the tools. The form and concepts used in these new tools and curricula have their basis in the notions put forward by Toulmin.

In the 1963 preface to the paperback edition of U of A, Toulmin (Toulmin 1958) suggested that he was gratified to be informed, five years after publication, of pragmatic value taken from the book. This paper attempts to update and explain some of the additional pragmatic effects for education that have been by tool creators and scientists in the almost fifty years since the work was first published.

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URL's

Belvedere
http://lilt.ics.hawaii.edu/lilt/index.html

Collaboratory Notebook
http://www.ls.sesp.nwu.edu/cnb/

CSILE
http://csile.oise.utoronto.ca/intro.html

Model-It
http://hi-ce.eecs.umich.edu/teacherworkroom/software/modelit/index.html

Palm Pilot Versions of Hi-C software

http://www.handheld.hice-dev.org/download.htm

Intermediate Models for Dynamic Processes
www.ncsa.uiuc.edu/edu/icm